THE EFFECT OF PID ON PHOTOVOLTAIC CELLS

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Abstract: This work deals with the Potential-Induced Degradation (PID) of the silicon photovoltaic modules and cells (PID shortly). The cause of PID degradation is in a migration of positive sodium ions from the protective glass, which was confirmed by the electroluminiscence measurements. The sodium drifts was locally supported by the increasing of the PV module temperature up to 80 °C. Based on the observation, a modification of the photovoltaic structure was added. The new solar cells shows good resisitive properties against PID.

Keywords: Potential-Induced Degradation, PV modules, Photovoltaic cells.

1 INTRODUCTION

Degradation of photovoltaic power plants due to the PID (Potential Induced Degradation) is one of the main degradation mechanisms, which is responsible for a reduction of the photovoltaic systems efficiency. The problems with PID were already known in the 1980 and currently is this topic widely researched through many scientists [1]. With the gradual increase of the production of photovoltaic modules and pressure to lowering the manufacturing costs began this undesirable phenomenon more frequent. The first company which warned about its negative effects was SOLON in 2010 and this has led to an increased awareness of PID [2]. A detailed study about the PID in photovoltaic modules has released two years later the Fraunhofer Institute in Germany. Fraunhofer Institute identified PID in 46% of tested modules from 96 different manufacturers [3].

1.1 POTENTIAL INDUCED DEGRADATION

The incidence of PID degradation is gradual and lasts for several years before it becomes fully observable - in extreme cases from 2 to 5 years. This degradation is accelerated by an environmental condition, such as humidity and heat. Therefore, the incubation time cannot be accurately determined and depends on the location and the conditions in which the photovoltaic modules operates.

The reason for the degradation process begins with the design of PV power plants with increasing performances, higher number of PV modules in series and higher potential between cells and grounded frame for security reasons. When using a floating potential (neither the positive or the negative pole of the string is grounded) a negative voltage potential arises at the negative pole, which causes the leakage currents from the PV cells passing through the sandwich structure of the PV module into the grounded frame. Conversely, the resulting negative electric field between the aluminum frame and the PV cells accelerates the movement of the positive sodium ions contained in the cover glass of the PV module that travel across the sandwich structure to the PV cells.

If the PV module is created with PV cells susceptible to the PID (they contain stacking fault in their *pn* junction) sodium ions will reduce shunt resistance R_{SH} and PV module performance will be lower. There are three levels in the protection against PID. The level of the whole photovoltaic system, the level of the photovoltaic module and the level of the photovoltaic cell.

To understand the occurrence of PID, the level of the photovoltaic cell is the most important. If the sodium ions get through the sandwich structure of the PV module up to the surface of the cell, they will drift by an electric field through an anti-reflective layer of silicon nitride SiN_x, where they will accumulate in the silicon oxide SiO_x layer. The presence of stacking faults through the PN junction allows the sodium ion further penetrate into the PV cell resulting in short-circuiting the PN junction. As a result of the above-described process, the value of the shunt resistence decreases and consequently the power of the whole PV cell is much lower.

Protection solution at this level is economically and technologically most acceptable because it does not interfere with the already functional PV system. It could be said that by modifying the technological process it is possible to modify the structure of the PV cell to be PID resistive.

PID protection and treatment at the levels of the PV module and the PV system is economically disadvantageous due to higher intervention and changes in their structure. At the level of the PV module is needed to find an alternative to Ethylene vinyl acetate film (EVA film) in the PV module sandwich structure. Alternative material must protect PV cells from external influences, ensure light transmission to cells and its resistance must be high enough to prevent drifting of the sodium ions to the PV cells. Material with the above-described properties is, for example, Acit (partially neutralized polyethylene). This material would meet the requirements, on the other hand its price is so high that the PV modules would be very expensive and it would reduce their competitiveness.

The research was divided into two parts. The first analyzed the effect of the temperature on the regeneration and degradation of photovoltaic module. The results confirmed drift of the sodium ions into the structure of the photovoltaic module. Based on this, we have proposed a modification of the photovoltaic cell manufacturing process to create PID-resistant photovoltaic "mini-modules".

2 RESEARCH AND RESULTS

2.1 INFLUENCE OF THE TEMPERATURE

Initial analysis were carried out on the photovoltaic module ES - A – 205, EVERGREEN. Evergreen module has been removed from the negative pole of the photovoltaic plant affected by PID. Parameters of the module before regeneration and degradation process are shown in Table 1. The measurements were done in certified laboratories CV-LAB at Brno University of Technology.

P_{MPP} (W)	E_{ff} (%)	U_{MAX} (V)	I_{MAX} (A)	U_{OC} (V)	I_{SC} (A)
179.9	11.4	17.3	10.5	22.3	11.9

Table 1: Parameters of the EVERGREEN PV module affected by PID**.**

The PV module maximum power decrease was 12.4% after five years of its operation. Power drop was caused especially by the PID degradation, which is confirmed by unchanged parameters of the PV modules from the positive pole of the string.

Workplace for the temperature influence investigation has been created in a dark room at the Department of Electrical and Electronic Technology, see Figure 1. Photovoltaic module was placed on the aluminum plate, which was under the entire surface of the module. Negative terminal of the DC power supply was connected on the aluminum plate and positive pole to the terminals of the module. Due to this connection was achieved an electric field in the opposite direction upon the PID affected photovoltaic power plant (solar cells was on the positive potential). Through the surface of aluminum sheet has been achieved a homogeneous electric field under the entire module. A DC power source was set to 600 V - chosen because of maximum value in the string according the manufacturer's manual. Local heating of the photovoltaic module was performed by the halogen lamp. Distance of the lamp was adjusted in the way that the temperature of PV module was 80 °C. Precise adjustment of temperature was measured using a thermocouple on the PV module surface.

Figure 1: Workplace for the regeneration of PV module.

Firstly was PV module regenerated and degradated only by an electric field and after several time intervals was added a local heating on the most affected solar cells. Electroluminiscence measurement and current-voltage characteristic were done after each time intervals. During regeneration by the electric field was the increase of the maximum power insignificant. Degraded PV cells were still noticeably dark. Later was applied local heating of the affected areas (80 ° C). Four regeneration steps measured by an electroluminescence are shown in figure 2.

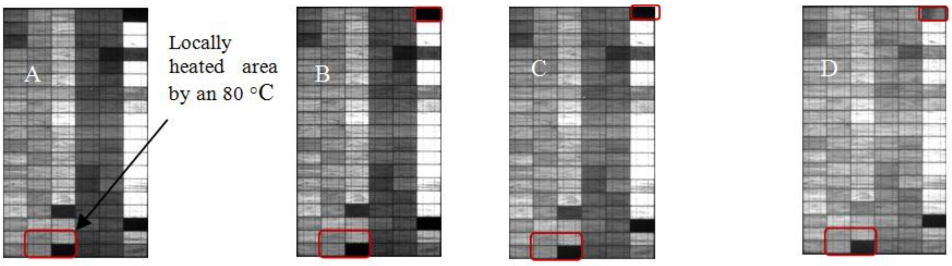

Figure 2: Electroluminescence images of regenerated PV module by an electric field (600 V) and with a local temperature of 80 °C: A - regeneration time 163 h., B - 187 h., C - 210 h., D - 306 h.

Locations of the PV module heated to 80 ° C with other PID degraded cells shows that the temperature accelerates regeneration. For steps B, C, D in Figure 2 were added another areas of local heating in the upper right corner of the PV module. Fig. 4 (D) shows the final state of the PV module after 306 h of regeneration. We are assuming that two dark cells are because of high degree of PID degradation, which is not reversible and therefore the regeneration process is ineffective. The characteristic of the PV module parameters on the time of regeneration are shown in the following graph, see Figure 3.

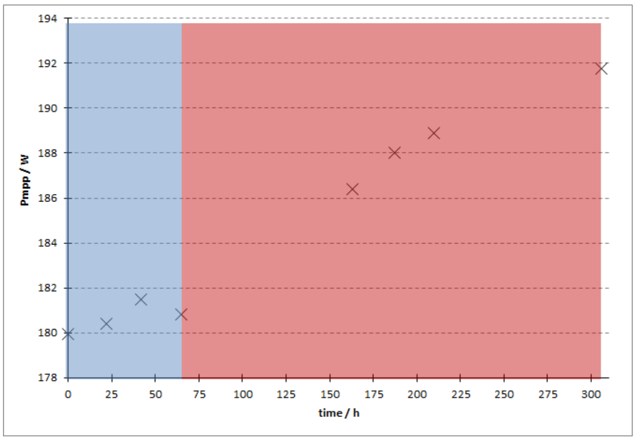

Figure 3: Dependence of the maximum power of the PV module at the time of regeneration (the blue area - regeneration with 600 V, the red area - regeneration with 600 V, 80 ° C).

The characteristic of the PV module regeneration has shown that the electric field has much less regeneration potential than regeneration with the areas heated to 80 ° C. This confirms the theory that heating of the affected areas noticeably accelerates regeneration process [2]. Temperature has increased the diffusion of sodium ions into the structure of the solar cell.

2.2 MODIFICATION OF THE PHOTOVOLTAIC STRUCTURE

Since temperatures of 80 ° C are commonly found on photovoltaic modules in their normal operation mode, it is necessary to decrease the accelerated penetration of sodium ions into the structure of photovoltaic modules. To prevent the entry of sodium ions was used layer of phosphorus silicate glass (PSG). PSG was applied during the solar cell emitter diffusion process. Since the process of manufacturing the PV cells has been modified, further steps of the process have been modified, such as an increase in the temperature of the diffusion step and the thickness of the antireflective layer. Because of the limited range of the publication, the process data will not be listed here. There will be shown only parameters of the reference photovoltaic cell and the newly created cell by the modified procedure - Table 2, together with the images of the compared structures, figure 4.

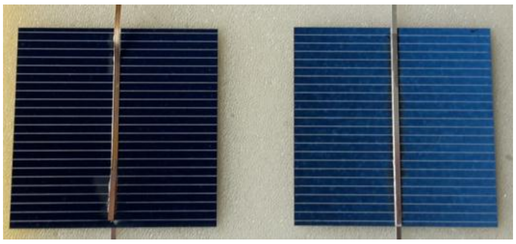

Figure 4: PV cells samples. Reference sample without PSG and with SiN_X layer 70 nm (left) and sample with PSG layer (right) with PSG and silicon nitride layer with thicknes (63 nm).

	I_{SC} (A)	V_{OC}(V)	I_{MAX}(A)	V_{MAX}(A)	P_{MAX}(W)	FF(%)
WithPSG	8.238	0.626	8.081	0.522	4.215	81.72
Without	8.233	0.625	8.084	0.525	4.244	82.48

Table 2. Parameters of reference sample without PSG with newly created sample with PSG

From the presented data it is clear that despite the intervention in the manufacturing process, it was possible to create the PV cells with their parameters corresponding to the reference samples. Further structure comparisons occurred through the electroluminescence measurement. The surface of the initial PV cells before the PID was free from any defects - both of the newly manufactured sample (A) and reference sample (B). The yellow section on both samples shows the area where the PID degradation was later created. As can be seen, after 210 hours of degradation, the effect of sodium ions only occurred on sample (B) without PSG layer, see Figure 5.

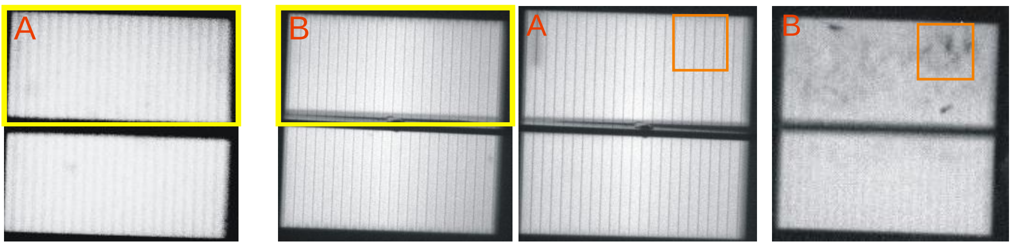

Figure 5: Electroluminescence images of samples A - New PSG layer sample, B – Reference sample. Electroluminescence images of PV cells after 210 hours of PID degradation. A - New PSG layer layer sample, B – Reference sample.

Measurements of IV characteristics in the dark was also carried out, see Figure 7. The characteristics again confirm the resistive properties of the PSG layer.

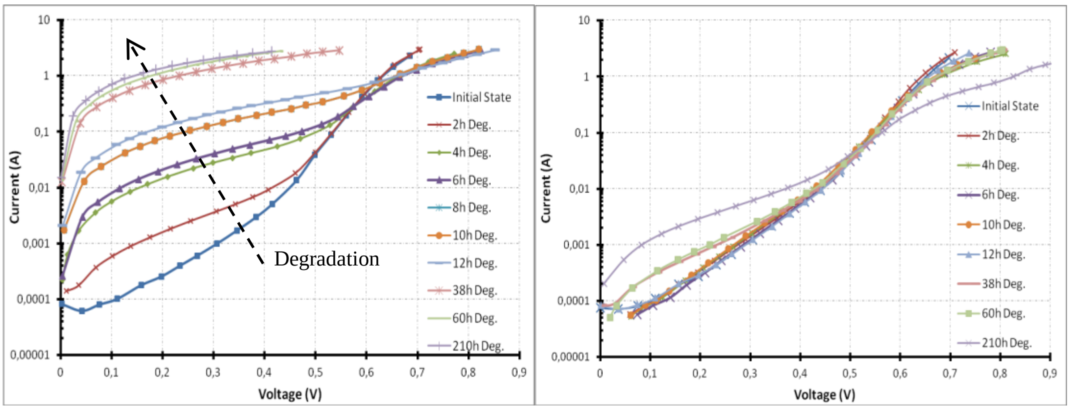

Figure 6: IV characteristics in the forward direction measured in the dark of the reference sample (A) and the newly formed sample (B) with PSG layer.

3 CONCLUSION

The aim of the work was to look at the PID in two ways. Confirm that the temperature accelerates the penetration of sodium ions into the structure of photovoltaic cells. For this purpose, a workplace was created and the effect of temperature on PID degradation was observed. Tested PV module (Evergreen) with the performance of 205 W has been uninstalled from the negative string of power plant. The module was PID degraded and regenerated again. It was found that the temperature rapidly accelerates the process of sodium diffusion, as can be seen from the dependencies in Figure 3. Temperature was increased locally at certain points of the PV module,so it was possible to compare these areas with the areas regenerated only by an electric field**.** Based on the findings, a new structure of sodium ion-resistant photovoltaic cells has been proposed. The structure of the photovoltaic cell has been modified by adding the PSG layer. The manufacturing process was then adjusted so that it does not interfere with the critical parameters of the photovoltaic cells – Table 2. The samples were further exposed to Potential Induced Degradation influence. From the measured results is visible PID resistive properties of the newly created samples, see Figure 6.

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